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Scientific/Clinical Article

Ultrasonographic median nerve changes under tendon gliding exercise in patients with carpal tunnel syndrome and healthy controls

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A B S T R A C T

Study design: Case control study.
Purpose of the study: To evaluate the ultrasonographic median nerve changes under tendon gliding exercise in patients with carpal tunnel syndrome (CTS) and healthy controls.
Methods: Seventy-three patients with CTS and 53 healthy volunteers were consecutively recruited. Each subject underwent a physical examination, nerve conduction studies and ultrasonographic examinations of the median nerve during tendon gliding exercises.
Results: Significant changes in the cross-sectional area of the median nerve were found while moving from the straight position to the hook position and from the hook position to the fist position. There were also significant changes in the flattening ratio when moving from the hook position to the fist position.
Conclusions: Ultrasonography revealed that the median nerve was compressed in the fist position in both CTS patients and healthy volunteers. Thus, forceful grasping should be avoided during tendon gliding exercises performed in the fist position.
Level of evidence: 3b

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Introduction

Carpal tunnel syndrome (CTS) is one of the most common entrapment neuropathies and the pathogenesis of idiopathic CTS is proposed to involve the increased pressure within the carpal tunnel arising from non-inflammatory tenosynovial swelling.[1,2] Histological studies have also demonstrated non-inflammatory fibrosis and thickening of the subsynovial connective tissue, which lies between the flexor tendon and the ulnar tenosynovial bursa inside the carpal tunnel.[3] The median nerve and the flexor tendons are connected by this multilayered subsynovial connective tissue. However, in patients with CTS, this connective tissue is thickened, which may restrict the gliding of the median nerve on both the transverse and longitudinal planes and induce continual trauma, even under normal movement of the limb.[4,5]

To reduce adhesions inside the carpal tunnel, tendon and nerve gliding exercises have been utilized as a component of combination treatments for CTS.[6–8] These exercises are expected to improve the symptoms by stretching the adhesions inside the carpal canal, reducing tenosynovial edema, improving venous return from the nerve bundles, and reducing pressure inside the carpal tunnel.[6,9] Although the therapeutic effects of these exercises remain inconclusive,[6–8,10,11] one previous study revealed that the functional improvement experienced by CTS patients when tendon gliding exercises were added to a standard treatment program was superior to the improvement following the addition of nerve gliding exercises.[12] Meanwhile, the excursion of the flexor digitorum superficialis and profundus tendons is nearly five times greater than that

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of the median nerve.[6,13] It is possible that tendon gliding exercises may redistribute the point of maximal compression on the median nerve inside the carpal canal by bringing the median nerve through its maximal excursion. Understanding the mechanism by which tendon gliding exercises affect the morphological change of median nerve could improve the clinical application of these exercises.

Although ultrasonography has been widely applied to evaluate the median nerve in patients with CTS,[14–16] few studies to date have evaluated the effects of tendon gliding exercises on the morphology of the median nerve. This study used commonly used ultrasonographical criteria, i.e., the cross-sectional area (CSA) and the flattening ratio (FR) of the long axis of the median nerve to the short axis, to evaluate the median nerve. Increases in the CSA and the FR of the median nerve have been demonstrated in patients with CTS, most likely as a result of swelling and compression of the median nerve under the transverse carpal ligament.[15,16]

Purpose

To obtain a better understanding of the dynamic changes of the median nerve during tendon gliding exercises, this study evaluated, by ultrasonography under rest and in five discrete positions of tendon gliding exercises, the morphological changes of the median nerve in patients with CTS and healthy volunteers.

Methods

This study consecutively recruited patients with CTS from the clinic of the physical medicine and rehabilitation department of a community hospital between October 2008 and December 2010. Healthy volunteers were recruited from the hospital staff and included volunteers and their friends. All of the subjects were invited to participate in the study on an entirely voluntary basis, and informed consent was obtained from each of the participants. Ethical approval to undertake this study was provided by our institutional review board. To be included, the patients were required to have: (1) subjective symptoms of tingling and/or numbness within the digits innervated by the median nerve, (2) either a positive Phalen sign or a positive Tinel sign, and (3) electrophysiological evidence of CTS from a nerve conduction study (NCS). The inclusion criteria for healthy volunteers included: (1) neither tingling nor numbness within the digits innervated by the median nerve, (2) both a negative Phalen sign and a negative Tinel sign, and (3) no electrophysiological abnormalities in the NCS of bilateral upper extremities. The exclusion criteria included the following conditions: (1) age <18 or >65 years; (2) cognitive disorders (e.g., mental retardation or dementia); (3) underlying medical disorders such as diabetes mellitus, renal failure, rheumatoid arthritis, hypothyroidism or other autoimmune diseases; and (4) pregnancy or previous wrist trauma or surgery.

The participants were asked to rate their pain intensity on a 0–100 visual analog scale. Every participant was submitted to a nerve conduction study (NCS) of the upper extremities and a series of physical examinations, which included Phalen sign, Tinel sign, the grasp/pinch strength test, and the Semmes-Weinstein monofilament sensory test. Sonography was performed on both wrists at rest and in five positions during the tendon gliding exercise.

Physical examinations

Phalen sign was conducted by fully flexing the patient's wrist for 60 s. The test was positive if the patient's symptoms in the median nerve distribution were reproduced.[17] Tinel sign was evaluated by tapping the median nerve along its course across the wrist. The test was positive if the patient experienced paresthesia in at least one of three radial digits.[17] Grip strength was measured using a handheld dynamometer, and palmar/lateral pinch strength was measured using a standard dynamometer between the tips of the thumb and the index finger. Each participant performed three recorded trials, and the mean score was recorded. The Semmes–Weinstein monofilament sensory test was conducted by applying force-calibrated monofilaments to each digit of the hand. A test was considered to be positive if the subject could verbally localize the digit that was receiving pressure with closed eyes, and a weighted score (1–5) was given to each filament according to the calculated force.[18] Scores obtained from seven sampling areas on each hand were totaled, and this total was analyzed as a continuous variable.

Nerve conduction study

All of the participants underwent median and ulnar nerve sensorimotor NCS utilizing Neuropack M1 MEB-9200 J/K electrodiagnostic equipment (Nihon Kohden Corporation, Tokyo, Japan) in a quiet, air-conditioned room (26 °C), with the subjects lying comfortably. The skin temperature on the hand was maintained higher than 32 °C. Standard techniques of supramaximal percutaneous stimulation, with a constant current stimulator and surface recordings, were used for NCS, as recommended in the literature.[19] At least one of the following criteria had to be met to confirm a clinical diagnosis of CTS: distal motor latency greater than 4.4 ms; distal sensory latency greater than 3.4 ms[20]; or a median-ulnar distal sensory latency difference, stimulated from the ring finger (ring difference), of greater than 0.4 ms.[21]

Tendon gliding exercises

The tendon gliding exercises were initially developed to reduce the adhesion of flexor tendons following trauma or surgery to the hand and wrist.[22,23] As shown in Fig. 1, the tendon gliding exercises used in this study involved sliding the flexor tendons of the hand by moving the fingers through five discrete positions: straight, hook, fist, tabletop, and straight fist positions.[23]

Ultrasonography

Ultrasonography was performed using a 12 MHz linear array transducer (GE LOGIQ 9, General Electric Medical Systems,

Fig. 1. The setup for ultrasound examination. The tested arm was positioned with the help of a wrist orthosis to ensure forearms supinated and wrists in neutral posture.

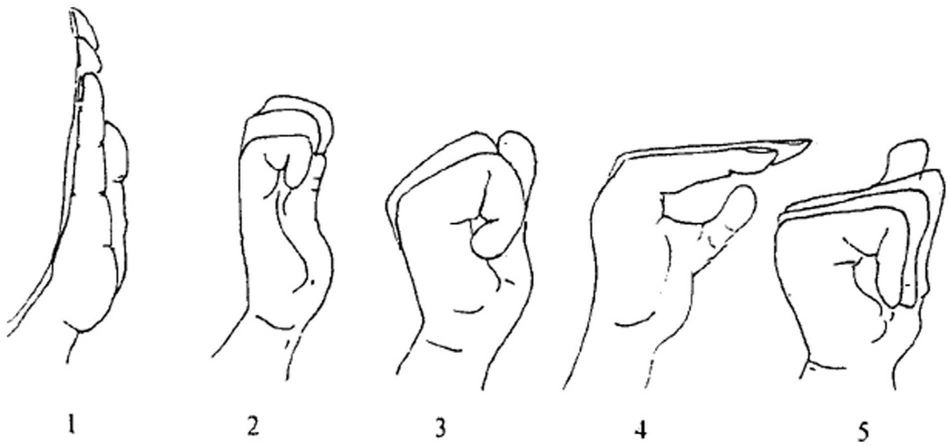

Fig. 2. The five positions in which fingers are placed in tendon gliding exercises: *1*, straight; *2*, hook; *3*, fist; *4*, tabletop; *5*, straight fist. Adopted from Akalin E, El O, Peker O, et al. Treatment of carpal tunnel syndrome with nerve and tendon gliding exercises. *Am J Phys Med Rehabil* 2002;81(2):108-113.

Milwaukee, WI, USA). The subjects were in the supine position with their arms extended, forearms supinated, and wrists and hands resting on a wrist orthosis in neutral position (Fig. 1). Pressure to the hand was avoided during the entire scanning process to minimize measurement errors arising from differences in loading, and the angle of the ultrasound beam was kept perpendicular to the surface of the nerve and tendon to obtain the highest echogenic view. Transverse ultrasonograms were obtained from the pisiform level under rest and in five discrete positions during the tendon gliding exercise as illustrated in Fig. 2. This study measured the CSA of the median nerve by tracing the margin of the inner border of the perineural hyperechogenic rim that surrounds the hypoechoic

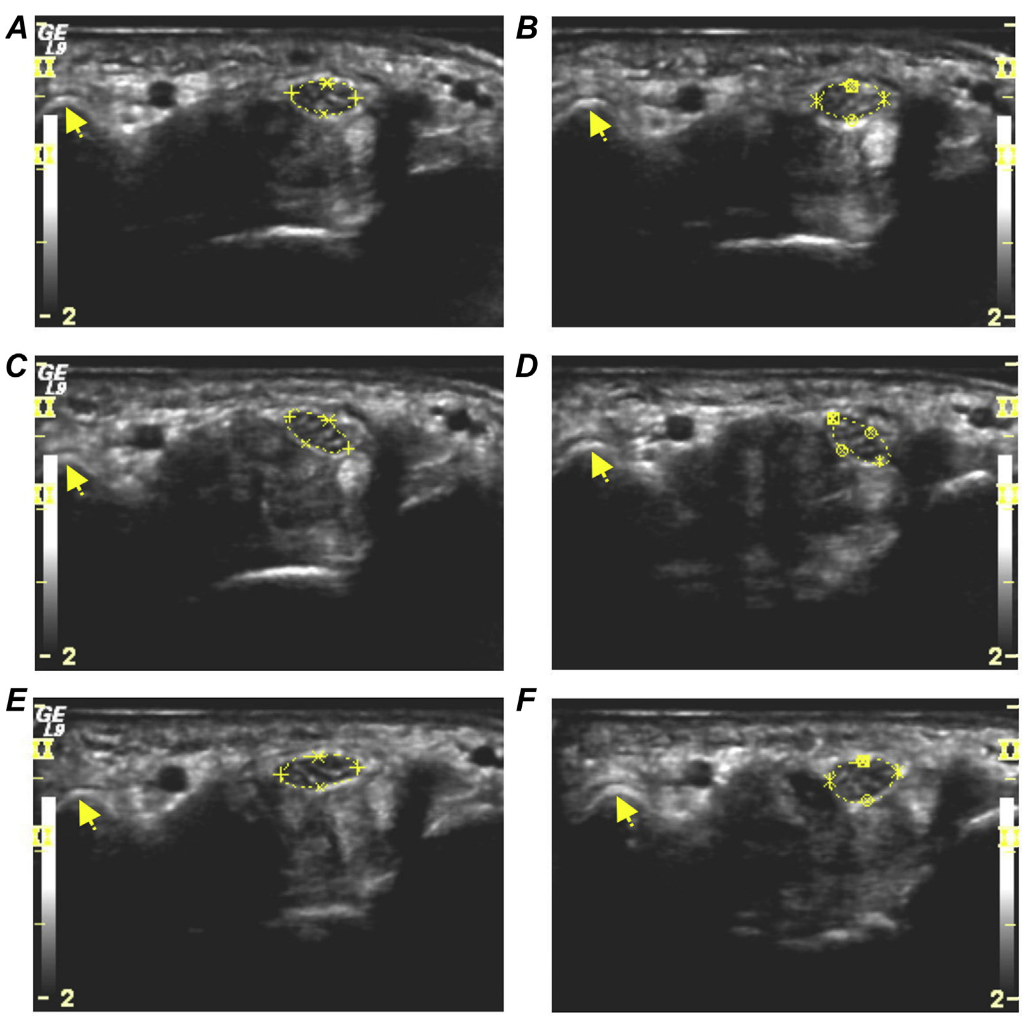

Fig. 3. The ultrasonographic images for one subject in 6 positions during tendon gliding exercises: A: resting, B: straight, C: hook, D: fist, E: tabletop, F: straight fist. The pisiform bone was marked by an arrow head and median nerve depicted.

Table 1
Demographic and clinical data for patients with carpal tunnel syndrome (CTS) and healthy volunteers ($N = 126$)

Characteristics	CTS patients $N = 73$ (%)	Healthy volunteers $N = 53$ (%)	P value
Personal characteristics			
Age	51.1 ± 9.2	48.8 ± 8.8	0.16
Female	67 (91.8)	47 (88.7)	0.56
Married	50 (69.4)	43 (81.1)	0.14
Employed	38 (52.1)	34 (64.2)	0.18
Smoking habit	5 (6.9)	1 (1.9)	0.40
Right-hand dominant	72 (98.6)	52 (98.1)	1.00
Unilateral hand involved R/L	16 (21.9)	–	–
Bilateral hands involved	57 (78.1)	–	–
Educational level			<0.01
College/University	24 (32.9)	33 (62.3)	
Senior high	31 (42.5)	14 (26.4)	
Junior high or below	18 (24.7)	6 (11.3)	
Household monthly income (US$)			<0.01
<1200	21 (29.6)	5 (9.4)	
1200–3500	38 (53.5)	27 (50.9)	
>3500	12 (16.9)	21 (39.6)	

median nerve and calculating the FR (Fig. 3).[15,16] All of the measurements were obtained by a physiatrist, who was also board-certified in ultrasonography and blinded to the clinical and NCS findings.

Statistical analysis

This study used Student's t test and the chi-square test to compare the demographic data between the two studied groups. Mixed effects model was applied for the results of the physical examinations. The examinations were performed on both hands for all of the participants. The group was treated as the fixed effect factor, the hand (left or right) was treated as a random effect factor, and the t test was used to compare the two groups. A repeated-measures analysis of variance (ANOVA) was performed to compare the changes in the CSA and the FR of the median nerve at rest and in the five positions during tendon gliding exercises. All of the statistical analyses were performed using the SAS statistical software package, version 9.2 (SAS institute Inc., Cary, NC, USA).

Results

Participants characteristics

In total, 126 participants (73 patients with CTS and 53 healthy subjects) were recruited consecutively between October 2008 and December 2010. Table 1 summarizes the demographic characteristics and basic information for the participants. As indicated in Table 1, the mean ages of the patients and healthy volunteers were 51.1 ± 9.2 and 48.8 ± 8.8 years, respectively. More than half of the CTS patients were female and had bilateral involvements. Statistical analysis indicated that there were no significant differences in age or sex between the patients and healthy volunteers. However, the healthy volunteers had higher educational levels and higher household income than the patients. The patients also had higher scores for pain intensity.

Physical findings and NCS

Comparison of the results of the physical examinations revealed significant differences between the two groups with regard to grasp power, palmar/pinch power, and the Semmes–Weinstein monofilament sensory test (Table 2). All of the NCS parameters were significantly different between the two groups.

Ultrasonographical findings

With regard to the ultrasonographical findings, the CSAs of the median nerves in all six positions in the patient group were significantly larger than those in the healthy volunteers (Table 3). Significant differences in the FR of the median nerve were also found in the straight and hook positions between the two studied groups. Furthermore, repeated-measures ANOVA was performed to compare the changes in the CSA and the FR of the median nerve in the six positions. The results revealed significant differences in the changes in the CSA and the FR of the median nerve in the six consecutive positions, and these differences were observed in both groups. Post hoc analysis revealed significant differences in the changes in the CSA of the median nerve from the straight position to the hook position and from the hook position to the fist position in both groups (Fig. 4). The changes in the FR from the hook position to the fist position were also significantly different in both groups, but significant change from the fist position to the tabletop position was only found in healthy volunteers (Fig. 5).

Discussion

In current study, we demonstrated the morphological change of median nerve at five postures during tendon gliding exercise. The cross-sectional area (CSA) of median nerve at pisiform level was significantly reduced at the fist position in both CTS patients and healthy volunteers. Prior studies have demonstrated changes in the CSA of the median nerve with specific finger and wrist motions,[24–26] but not specifically during positions utilized for tendon gliding exercises.

Reduced gliding of the median nerve in the carpal tunnel is observed in CTS patients,[27] which is the theoretical basis of tendon gliding exercise. Hypothetically, the longitudinal excursion of the median nerve could provide maximum differential gliding for both flexor tendons and prevent the formation of adhesions. Meanwhile, finger or wrist motions are associated with movement of median nerve within carpal tunnel and also deformation of median nerves.

Table 2
Comparison of clinical indicators of physical examinations and nerve conduction studies between hands with carpal tunnel syndrome (CTS) and healthy hands

Variables	Patients with CTS (patients/hands = 73/130)		Healthy volunteers (persons/hands = 53/106)		P value
	Mean	SD	Mean	SD	
Monofilament test	30.1	3.4	33.2	2.1	<0.01
Grasp power (kg)	40.9	14.4	52.2	15.3	<0.01
Palmar pinch power (kg)	7.1	3.4	8.7	2.8	<0.01
Lateral pinch power (kg)	9.8	4.5	12.6	3.6	<0.01
Distal sensory latency of median nerve (ms)	3.6	1.0	2.7	0.4	<0.01
Distal motor latency of median nerve (ms)	5.0	1.1	3.5	0.3	<0.01
Ring difference (ms)	1.0	1.1	0.04	0.3	<0.01

Table 3
Comparison of results of ultrasonography between patients with CTS and healthy volunteers

Variables	Patients with CTS (patients/hands = 73/130)		Healthy volunteers (persons/hands = 53/106)		*P* value
	Mean	SD	Mean	SD	
CSA of median nerve (mm^2)					
Resting	11.3	3.2	8.3	1.8	<0.01
Straight	11.8	3.7	8.6	2.0	<0.01
Hook	11.3	3.8	8.3	2.0	<0.01
Fist	11.5	4.1	8.5	2.1	<0.01
Tabletop	11.6	3.9	8.2	1.8	<0.01
Straight fist	11.6	3.9	8.4	2.0	<0.01
Flattening ratio					
Resting	2.9	0.8	2.7	0.7	0.14
Straight	2.9	0.9	2.6	0.8	0.03
Hook	2.8	0.8	2.5	0.7	0.04
Fist	2.9	0.8	2.8	0.8	0.36
Tabletop	2.9	0.8	2.7	0.8	0.14
Straight fist	2.9	0.8	2.8	0.8	0.43

CSA, cross-sectional area.

In order to understand how the deformation developed along the course of tendon gliding exercise, we studied five discrete postures during the tendon gliding exercise, including straight, hook, fist, tabletop, and straight fist positions. These postures involved flexion of variable finger joints, for example, flexion of proximal interphalangeal (PIP) and distal interphalangeal (DIP) in hook, metacarpophalangeal (MCP), PIP and DIP in fist and straight fist, and MCP in tabletop posture. Our study revealed significant increases in the FR of the median nerve in both groups when the participants made a fist from the hook position (Fig. 1) and it implies that the median nerve was further compressed into an elliptical shape in this position. Although performing the hook, fist, and straight-fist positions during tendon gliding exercises can result in maximal differential gliding of both the flexor digitorum superficialis and profundus tendons,[22] forceful formation of a fist may induce migration of the lumbricalis muscles into the carpal tunnel and further aggravate the compression of the median nerve. Moreover, proximal gliding of the flexor tendons progresses when effort is added gradually.[13] Another study also demonstrated that median nerve slips away from the flexor tendons and moves either ulnarly or radially and causes mechanical nerve deformation when a fist is made, due to compression against the flexor retinaculum by tensed overlying flexor tendons.[24] Therefore, forceful fist formation is not recommended for avoiding compression of the median nerve.

This study also found that the CSA of the median nerve was increased from rest to the straight position, which corroborated previous findings that the CSA of the median nerve was larger in the finger extension position than that in the finger flexion position.[28] This increase in CSA may have occurred because the carpal tunnel space was increased by sliding the flexor tendons distally when the fingers were fully extended. The CSA of the median nerve was then decreased when the subsequent hook position slid the flexor tendons into the carpal tunnel proximally. This phenomenon was observed in patients with CTS and in healthy volunteers. Because the carpal tunnel contains two synovially lined bursae, flexor tendon movement is associated with both synovial and paratenon-related (extrasynovial) sources of friction.[29] Thus, tendon gliding exercises may not only provide maximum differential gliding for both flexor tendons but may also stretch the interconnecting collagen fibers in the subsynovial connective tissue and improve synovial fluid lubrication in the carpal tunnel bursae.[13,29] This study demonstrated by ultrasonography the effects of tendon gliding exercises on the transverse aspect of the median nerve. Further studies are recommended to evaluate the effects of

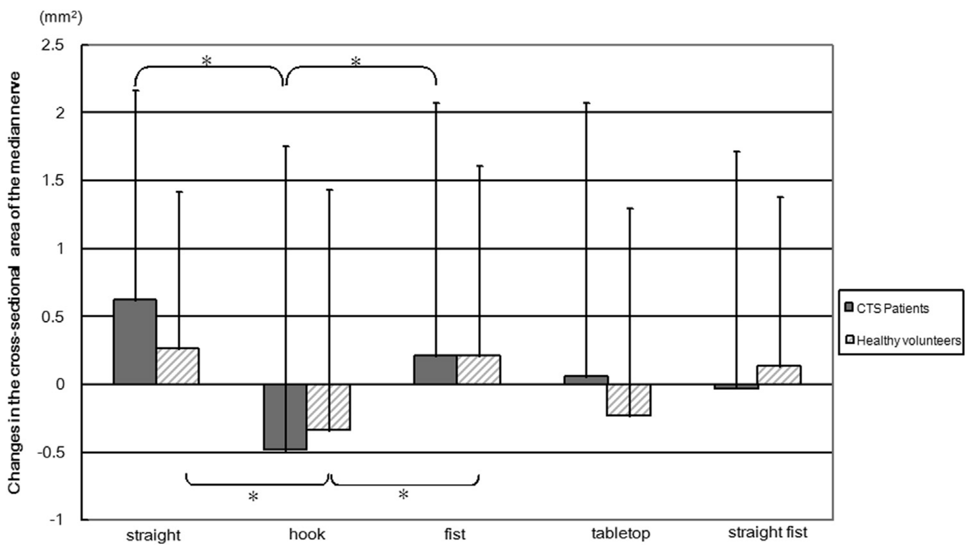

Fig. 4. Changes in the cross-sectional areas of the median nerve from the rest position to the subsequent five positions (i.e., straight, hook, fist, tabletop, straight fist) in which fingers are placed in tendon gliding exercises. * refers to significant difference between two positions.

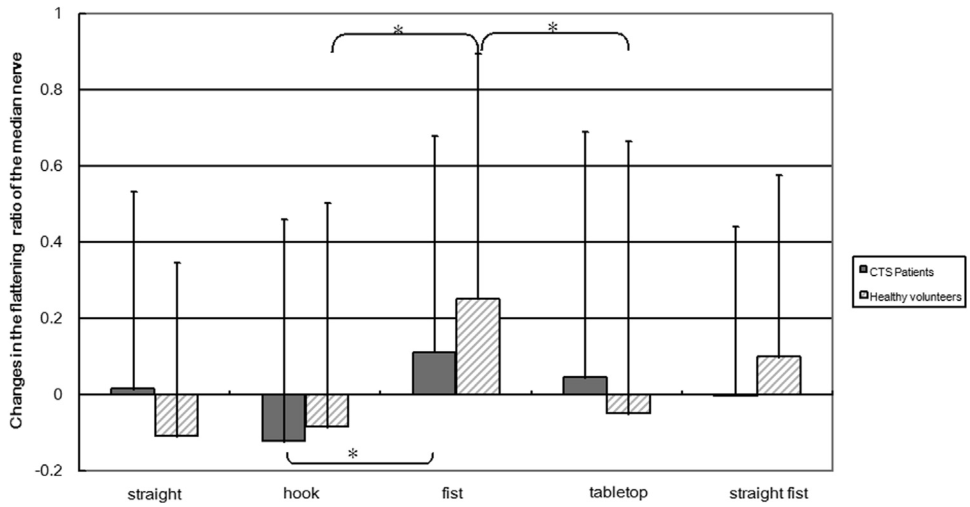

Fig. 5. Changes in the flattening ratio of the median nerve from the rest position to the subsequent five positions (i.e., straight, hook, fist, tabletop, straight fist) in which fingers are placed in tendon gliding exercises. * refers to significant difference between two positions.

tendon gliding exercises on the longitudinal gliding of the median nerve.

This study also revealed that the CSA in the patient group was significantly larger than that in the control group, either in a resting position or in the five positions of the tendon gliding exercises, as shown in previous studies.[15,16] The FR of the median nerve in the CTS group was also larger than that in the control group, although significant differences between the groups were only found in the straight and the hook positions during the tendon gliding exercises. These findings can be regarded as a validation of the baseline measurements used for this study.

Study limitations

First, the flattening of the median nerve could have been affected by the pressure transmitted from the probe during the sonographic examination. Thus, gel standoff technique was applied to reduce this potential bias. Second, this study did not apply an electrogoniometer to record the range of finger motion simultaneously. However, to minimize the error contributed by this factor, a wrist orthosis was used to immobilize the wrist joint in a neutral position while recording. The neutral position was selected because the gliding resistance of the flexor tendon in the wrist is minimized in this position.[29] Third, the force used while performing a hook and making a fist was not measured or controlled, which may have increased the variability of the measurements obtained in these positions. To minimize the variability of force during grasping, all of the subjects were instructed to maintain the hook and fist positions with minimal force. Additional studies are warranted to explore the relationship between morphological changes of the median nerve and the magnitude of grasping force.

Conclusion

Ultrasonography revealed that the median nerve was compressed in the fist position in both CTS patients and healthy volunteers. Thus, forceful grasping should be avoided during tendon gliding exercises performed in the fist position.

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#1. Inclusionary criteria for the CTS group included all but
  a. abnormal NCS findings
  b. a positive Phalen or Tinel sign
  c. abnormal Semmes Weinstein scores
  d. parasthesias or numbness in the median nerve distribution

#2. Subjective pain scores were made on a scale of
  a. 0–100
  b. 0–10
  c. least to worst
  d. none of the above

#3. The median nerve was evaluated for relative flattening in the _______ digital posture
  a. straight fist
  b. hook fist
  c. full fist
  d. all of the above

#4. The authors' primary interest was to determine the median nerve's dynamic behavior during
  a. resisted fisting
  b. the Phalens position after 60 seconds
  c. the performance of nerve gliding exercises
  d. the patient's occupation

#5. The authors suggest that patients refrain from forceful fisting when performing nerve gliding exercises
  a. false
  b. true

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